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PROJECT MEMORANDUM

To:	**Faro Mine Closure Planning Office**	**Fax No.:**	
Attention:	**John Brodie**	**CC:**	**Rock Drain Working Group**
From:	**Gerry Ferris**	**Date:**	**February 8, 2006**
Subject:	**Estimated current flow through capacity, Rev A for review**		
No. of Pages (including this page): 9		**Project No:**	**0257-031-01**

This memorandum is part of a series that will be sent to the Rock Drain Working Group to describe the analysis being undertaken for the North Fork Rock Drain (NFRD). This third memorandum combines the monitoring program results (from memo 2) with the theoretical background (memo 1) in order to estimate the current flow through capacity of the NFRD.

The purpose of this series of memoranda is to provide a description of the work being performed and to allow comments from members of the working group to be incorporated prior to preparation of the draft report. The memoranda planned for this series are:

- Memorandum 1 – Flow through rockfill, Theoretical Basis – Issued for review, January 16, 2005
- Memorandum 2 – NFRD, Measured flow through – Issued for review, January 26, 2006
- Memorandum 3 – Estimated current flow through capacity
- Memorandum 4 – Stability of NFRD under flow through conditions
- Memorandum 5 – Estimated future flow through capacity

1.0 INTRODUCTION

The purpose of this memorandum is to provide a methodology for estimating the current flow through capacity of the NFRD. The first memorandum (BGC 2006a) provided a theoretical basis for flow through rockfill and the second (BGC 2006b) summarized the measured flow through in 2005. This memorandum contains further analysis and discussion of:

- The 1986 design basis of the NFRD with respect to flow through capacity.
- A discussion concerning use of the 2005 data for predicting the flow through relationship,
- The estimated current flow through capacity of the NFRD, and
- The estimated discharge through the NFRD and the resulting pond water elevations for the probable maximum flood (PMF).

This memorandum is concerned only with prediction of the current capacity of the NFRD. The possibility of future changed conditions is the subject of Memorandum 5.

2.0 1986 FLOW THROUGH RELATIONSHIP

The NFRD was designed in 1986 (Golder 1986) to transmit the flow of the North Fork Rose Creek through the rockfill embankment constructed as part of the haul road to the Vangorda mining area. At this time the use of a rock drain was a relatively new concept in Canada, with the first rock drain being constructed in 1981 (Campbell 1985). The design of the NFRD conservatively considered that the only area contributing to flow through the structure was a 70 m wide 3.6 m high zone of dumped, coarse calc-silicate rockfill centered on the existing creek. Using this conservative assumption the cross-sectional area available for flow through the embankment was 250 m^2.

The methodology for calculating the discharge through the rockfill was not stated in the design document, however it was stated that the flow will depend on the:

a) Mean size of the rock fragments comprising the drain
b) The voids ratio
c) The surface roughness of the constituent rock fragments
d) The hydraulic gradient, and
e) The gross cross-sectional area of the drain.

It was then considered that factors a, b c and e were constant, so that that discharge through the NFRD would be related only to changes in gradient. The initial gradient was 1.3%. It was considered that the gradient would increase with increasing pond height. The resulting predicted discharge through the NFRD is shown in table 1.

Table 1 1986 Relationship Between Pond Height and Discharge

Pond Height (m)	Discharge (m^3/s)
2.5	2.5
5	5
10	7.5
15	9
20	10.5
25	12
30	16

Using this relationship between discharge and pond height, the pond water level was predicted reach a maximum depth of 11 m for the average annual flood (7 m^3/s) and 40 m for the 100 year flood (70 m^3/s). After the 1988 spring freshet this design relationship was abandoned and a new relationship created to describe the flow through relationship based on the measured data (Golder 1988). Three different relationships between pond depth and discharge were developed based on measurements taken at the NFRD (two in 1988 and 1993), Figure 1. The 1988 relationships were based on power law curve fitting of the measured pond levels and corresponding discharge and the 1993 relationship was based on a quadratic curve fit.

The reason that the original design relationship was abandoned was never discussed in the later memorandum prepared concerning the NFRD. Based on the pond water depths and the discharge measurements collected however, the original relationship was determined to be too conservative. The typical maximum pond water depth measured was 4 to 5 m not 11 m as predicted by the original relationship. Measurements collected throughout 2005 (Figure 2) further confirms that the original relationship did not correctly describe the flow through capacity. In 2005 the maximum discharge was 22 m^3/s and the pond was about 8 m deep, whereas the original relationship would have predicted about 40 m depth. The reason for this large discrepancy is likely due to the conservative assumption about the area available for flow through. Other factors like grain size and voids ratio may also play a role.

3.0 DISCUSSION OF 2005 MEASURED FLOW THROUGH RELATIONSHIP

During 2005 the pond water elevation and the creek discharge downstream of the NFRD was measured (BGC 2006b). The resulting relationship between the pond water elevation and discharge measured downstream of the NFRD is shown in Figure 2. The pond levels included in the 2005 data set are the highest levels experienced to date by the NFRD.

In the first memorandum for the NFRD (BGC 2006a) the theoretical relationship between the pond elevation and discharge through the structure was noted to be related to:

- Dimension of the structure,
- Hydraulic gradient developed in the structure (dependent on both the dimension and the permeability of the materials),
- Material properties (grain size, density and angularity which control the permeability of the material), and
- Available area for water flow (this is a function of both the raw area and the voids within the rockfill through which water can flow).

The available data to describe the above properties are discussed below to provide context to the expected accuracy of the predictions.

Dimensions

The upper dimensions of the NFRD are taken from a digital terrain model (DEM) with 2 m contours based on 2003 airphotos. The 2003 airphotos were taken when the water elevation in the pond on the upstream side of the NFRD was at elevation 1091 m amsl. The information on the dimensions of the NFRD developed from the 2003 DEM was supplemented by pre-mining topography, also based on airphotos that has 25 foot (7.62 m) contours. Based on the methodology used in the creation of the DEM's, the storage capacity (Figure 3) and the flow through areas for both the entire embankment face and the calc-silicate zone only (Figure 4) are considered reliable only above 1091 m amsl.

Material Properties

The permeability of the rockfill is controlled by three main material properties; the dominant grain size, D_{50}, the porosity and angularity. The angularity of the calc-silicate is likely similar to 'typical' blast rock (equal dimensional) but the schistose type rock will likely be more tabular than 'typical'. Limited information is available on the grain size and its variation through the structure. The typical pattern of segregation of dumped rockfill is however apparent at the NFRD, with the largest sizes collected at the base, becoming progressively finer grained towards the crest. No direct information is known about the porosity.

Hydraulic Gradient

The hydraulic gradient is a function of the net hydraulic head across the structure and the length of the flowpath. Both of these parameters may vary depending on the volume of water entering the pond, the geometry of the structure and the hydraulic properties of the NFRD. Hydraulic gradient is therefore subject to the uncertainties in the estimation of the material properties noted above.

Area Available for Water Flow

The area available for flow is related to both the total area and the porosity. The total area is thought to be reasonably accurate only above elevation 1091 m amsl.

A separate project constraint is that the pond elevation behind the NFRD should not be allowed to be higher than 1125 m amsl. The elevation at which water will begin to flow into the buried Zone II pit is 1128 m amsl (ICAP 1996). The cross-sectional area available for flow at elevation 1125 m amsl is about 17,000 m^2. The maximum pond elevation measured in 2005 was 1097 m amsl which results in a flow area of about 1,200 m^2 or 7% of the amount available for a pond elevation of 1125 m.

With the unknowns related to material properties of the rockfill and the expected accuracy of the flow through area below 1091 m amsl it is considered unlikely that definitive conclusions can be reached about the flow-through properties of the NFRD. The most likely source of errors is related to the flow through areas. The best estimate of the current flow through capacity of the NFRD below elevation 1097 m amsl is presented in Figure 2.

4.0 FLOW THROUGH RELATIONSHIP

As indicated above, the flow through relationship below pond elevation 1097 m amsl was measured in 2005. This data set represents the best estimate of the flow through capacity available to date. As noted above, it is, however, considered unlikely that a definitive flow through relationship for the entire embankment can be established based on pond levels below 1097 m amls. Many combinations of flow area, voids ratio and grain size could result in the same elevation- discharge relationship. Also, there is uncertainty regarding the proportions of flow through that are occurring within the actual drain section, versus the surrounding embankment fill.

The 2005 data set is considered representative of only 7% of the area required to develop a full flow through relationship between elevation 1097 and 1125 m amsl. Therefore, the predicted flow through relationship for the majority of the embankment must be based on assumptions.

Previously Golder fitted the measured pond and discharge data using either a quadratic or a power law relationship. The 2005 data (Figure 2) was curve fitted with a quadratic equation and simply extended up to elevation 1125 m amsl (Figure 5). It is unclear if this relationship, developed on the basis of the low flows is valid, since the flow in the upper elevations will depend on area of flow and the material properties in this zone.

The first rock drain installed in Canada was constructed in 1981 (Campbell 1985) and was monitored to determine the flow through characteristics of the structure. The results of this monitoring over a period of four years indicated that the average discharge capacity was between 0.031 to 0.22 $m^3/s/m^2$ (Campbell 1985). The results of the 2005 discharge monitoring at the NFRD were calculated and plotted in a similar manner, discharge per unit area, in Figure 6. The area relationship from Figure 3 was used direction for this calculation. The unit discharge measured during the 2005 monitoring program varied from 0.01 to 0.02 $m^3/s/m^2$ above elevation 1091 m amsl. Using these two unit discharges and the total area of the embankment (Figure 3), discharge is calculated and plotted in Figure 7 along with the quadratic fit from Figure 5. The plot shown in Figure 7 shows an extremely large variability in the predicted flow. Again, it is not clear from this data which of these relationships would best represent the NFRD, taking into account the various factors.

The information presented in Memorandum 1 (BGC 2006a) outlined a methodology for calculating the flow through capacity of the NFRD. As outlined in this memorandum there are many factors which must be estimated in order to make a prediction. Given the unknowns and the variety of flow through relationships that could be made from simple curve fitting, it is thought that no single 'best estimate' for the flow through relationship is possible. Instead three potential scenarios are considered; high flow, medium flow and low flow.

- The high flow scenario was created by assuming that the rock size for the entire embankment was 0.25 m and the voids ratio was 0.4. This high estimate was created to attempt to calculate the highest flow through capacity that could be conceived.
- The medium flow scenario assumes that the rock within the 70 m wide calc-silicate zone had a diameter of 0.125 m and the schistose rock had a diameter of 0.05 m. This medium case assumes that the rock size is considerably smaller than measured in the calc-silicate zone and very low rock sizes in the schistose type zone. This scenario also assumes that the material making up the NFRD is rockfill with limited fines content.
- The low flow scenario was created by assuming that the rock within the 70 m wide calc-silicate zone has a diameter of 0.25 m and no flow occurs through the schistose rock. In this scenario, all the flow will be through the 70 m wide drain zone only. This estimate of flow is thought to be an extreme case since some flow is expected to occur through the schistose type rock.

In order to calculate a elevation discharge relationship the NFRD embankment was split into a 70 m wide calc-silicate zone and the remaining 1.1 km face area was split into 100 m segments. For each segment the gradient acting on the segment was calculated separately and only began contributing flow once water elevation in the pond was above the base of that particular segment. These three elevation discharge relationships are shown in Figure 8.

5.0 HYDRAULIC ROUTING

The relationships shown in Figure 8 were provided to nhc. Nhc then used these relationships to route the PMF through the structure. The results are shown in Figure 9 and 10 for the discharge and maximum pond elevations respectively.

This routing shows that the NFRD would reduce the peak flow of the PMF from 384 m^3/s to somewhere between 141 and 271 m^3/s, depending on the flow through relationship. The high flow estimate (which was based on large free draining rocks being present throughout the embankment) produces maximum flooding downstream so should be used for the design of the RCDC upgrading work.

These results indicate that although there are very significant differences in the flow through relationships only minor differences exist between the pond elevations calculated for the majority of the flood event, since the outflow rate is high enough in all cases that the inflow to the system dominates the results. Near the peak flood event the differences are much more apparent for pond elevation. Although this routing shows that the pond elevation will not exceed about 1120 m amsl, the stability of the NFRD should be assessed as if the water can reach elevation 1125 m amsl.

6.0 Discussion

Based on the overall area of the NFRD that could be subjected to flow through under PMF conditions, versus the area for which a discharge relationship has been measured, it is apparent that prediction of the flow through capacity will be uncertain due to the potential wide range of of structure properties that have to be estimated. As a result, three flow through scenarios were created in order to bound the possible range of flow through relationships. When these different flow through relationships were used, it was found that the discharge capacity did not have a significant effect on upstream pond levels. This would indicate that for the scenarios considered, the pond level is determined primarily by the inflow rate and is relatively insensitive to the flow through capacity. .

7.0 REFERENCES

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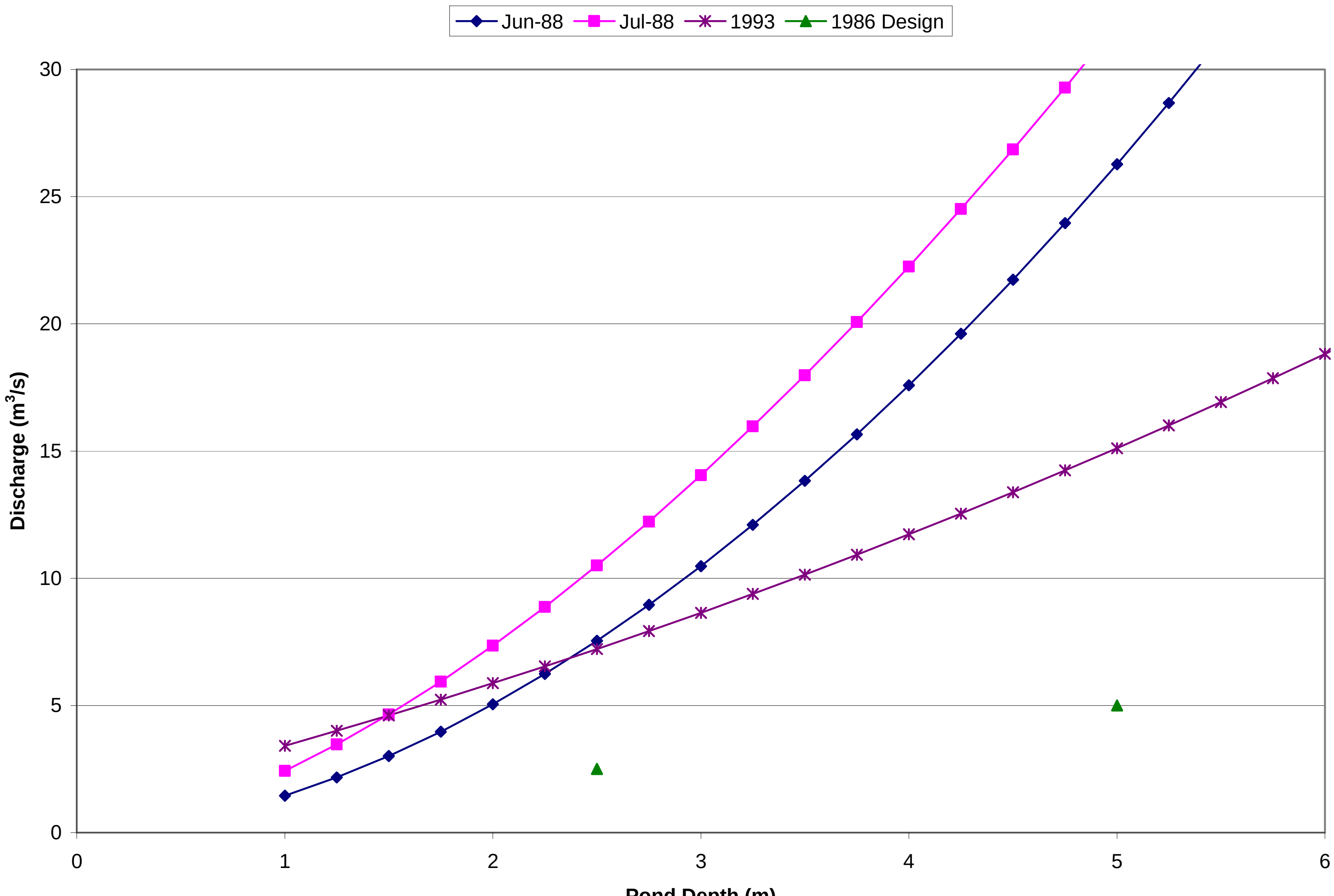
FIGURES



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Client: Deloitte & Touche

Project: TASK 22F – 2005 ROCK DRAIN ANALYSIS

Title: 1986 DESIGN FLOW THROUGH AND THREE ADDITIONAL RELATIONSHIPS DEVELOPED

Project #:	Date:	Scale:	Drawn:	Approved:	Figure:
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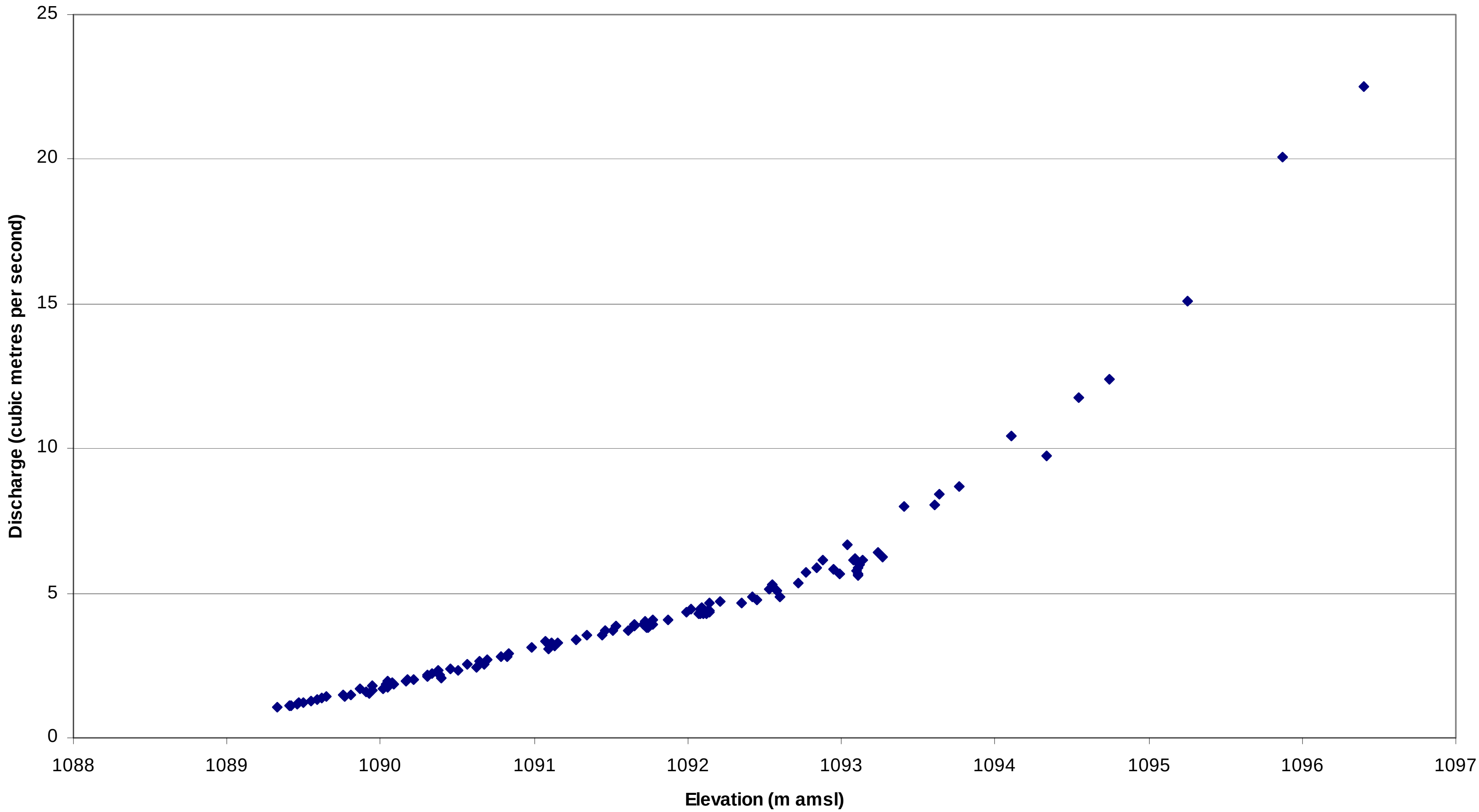

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Project: TASK 22F – 2005 ROCK DRAIN ANALYSIS

Title: MEASURED POND WATER ELEVATION AND DISCHARGE

Project #:	Date:	Scale:	Drawn:	Approved:	Figure:
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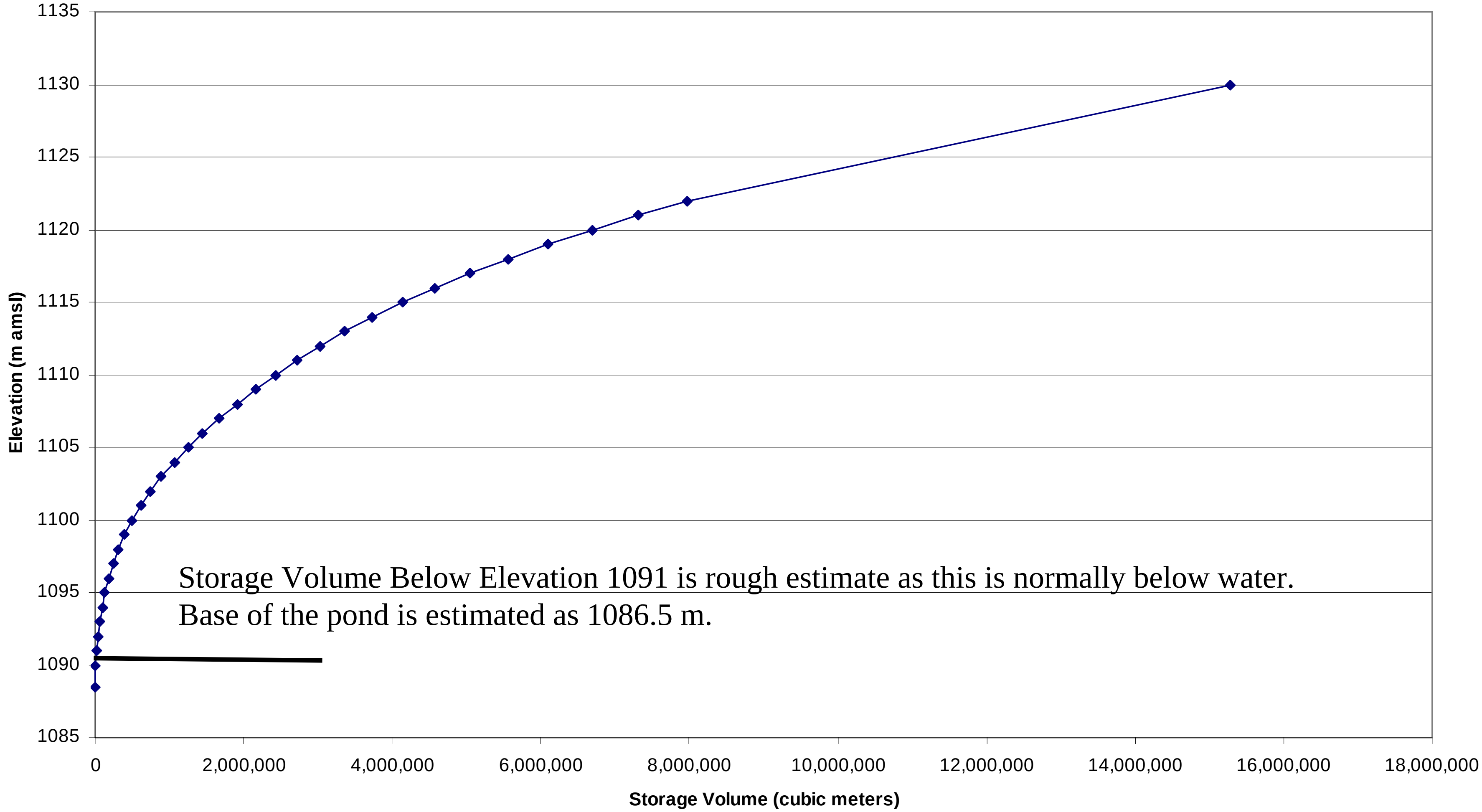

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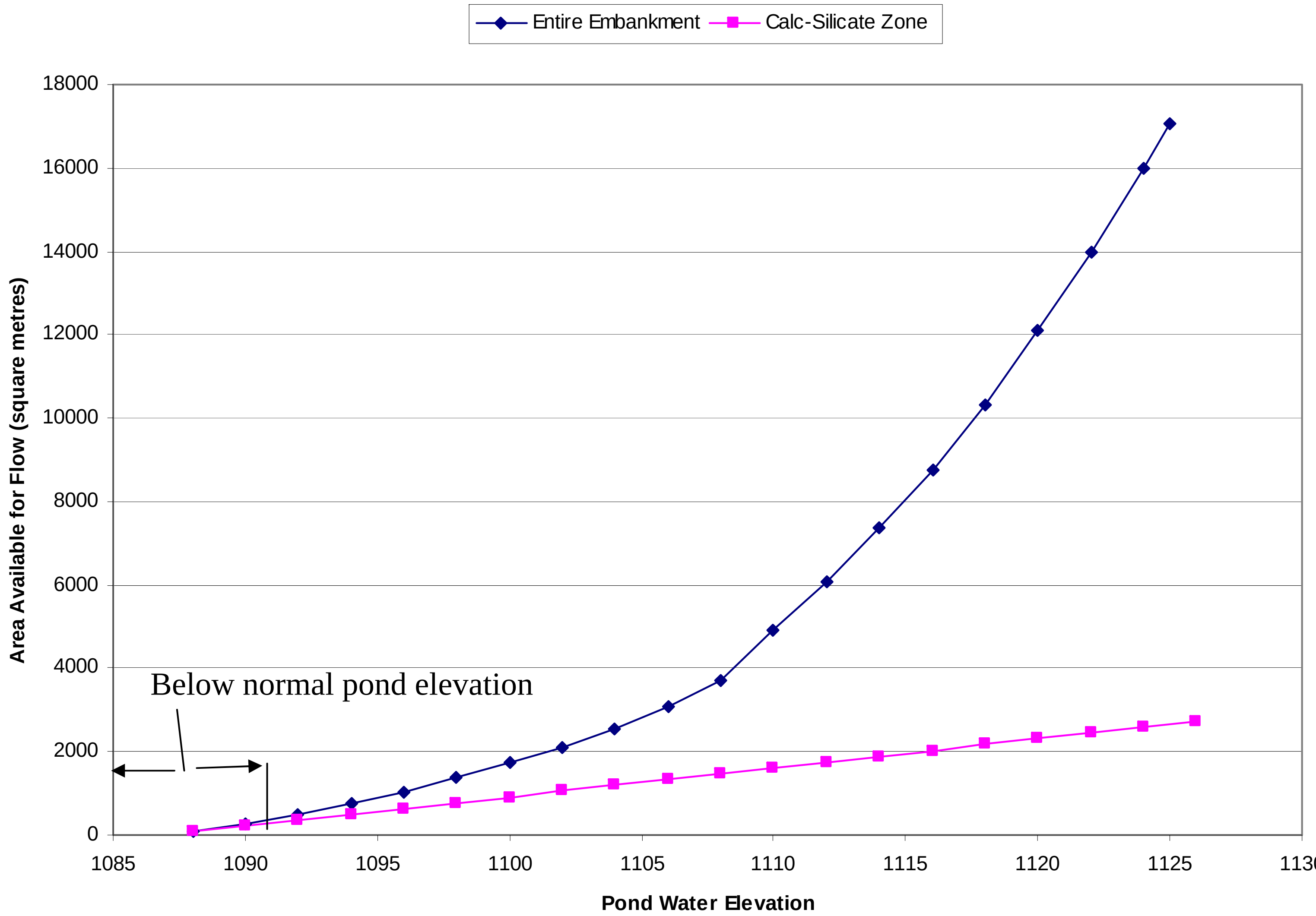
Project: TASK 22F – 2005 ROCK DRAIN ANALYSIS					
Title: STORAGE CAPACITY CURVE – NFRD POND					
Project #: 0257-031-01	Date: JAN 2006	Scale: NA	Drawn: GWF	Approved:	Figure: 3



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Project:	TASK 22F – 2005 ROCK DRAIN ANALYSIS
Title:	FLOW THROUGH AREA OF EMBANKMENT

Project #:	Date:	Scale:	Drawn:	Approved:	Figure:
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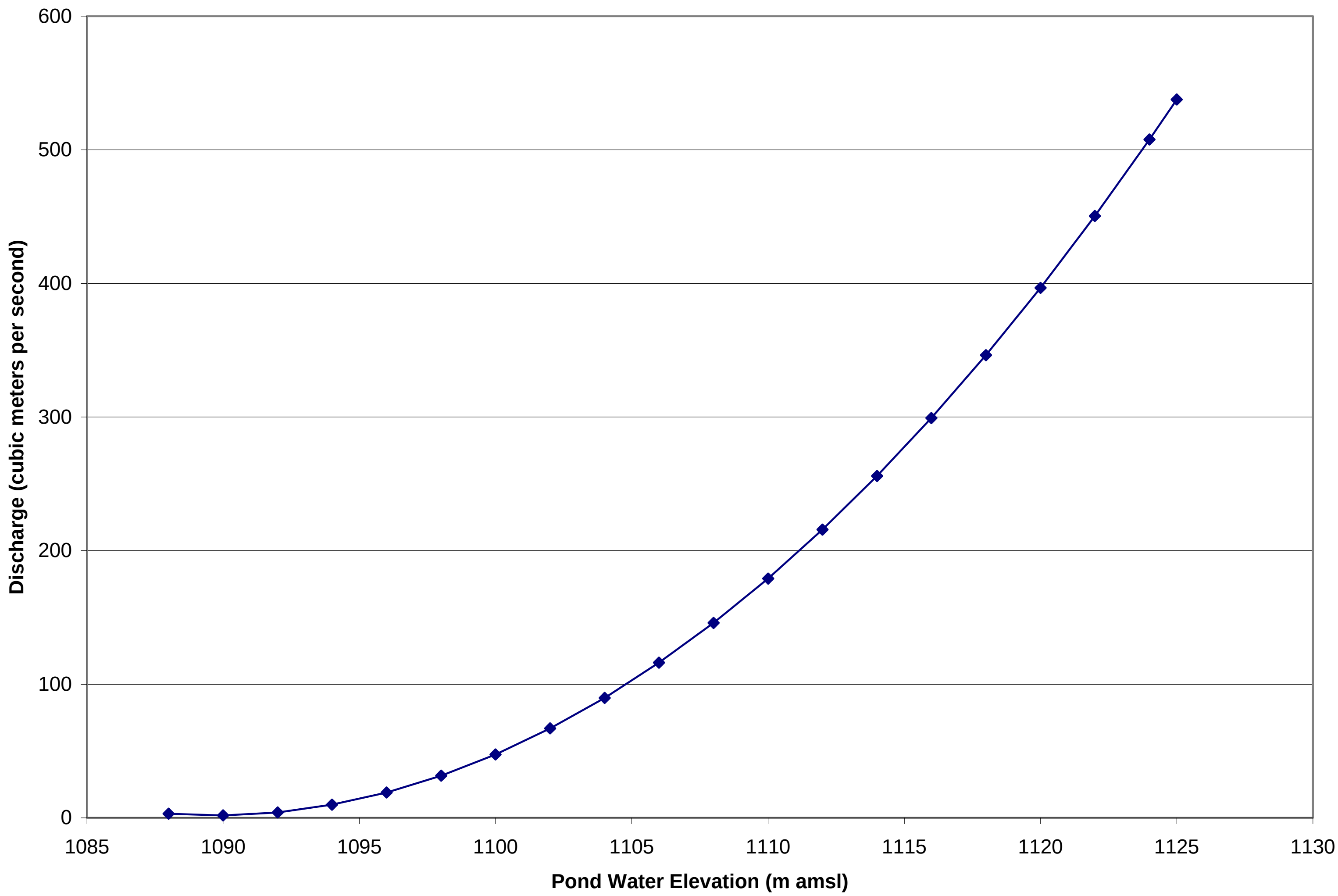

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Project: TASK 22F – 2005 ROCK DRAIN ANALYSIS

Title: QUADRATIC FIT OF 2005 DATA

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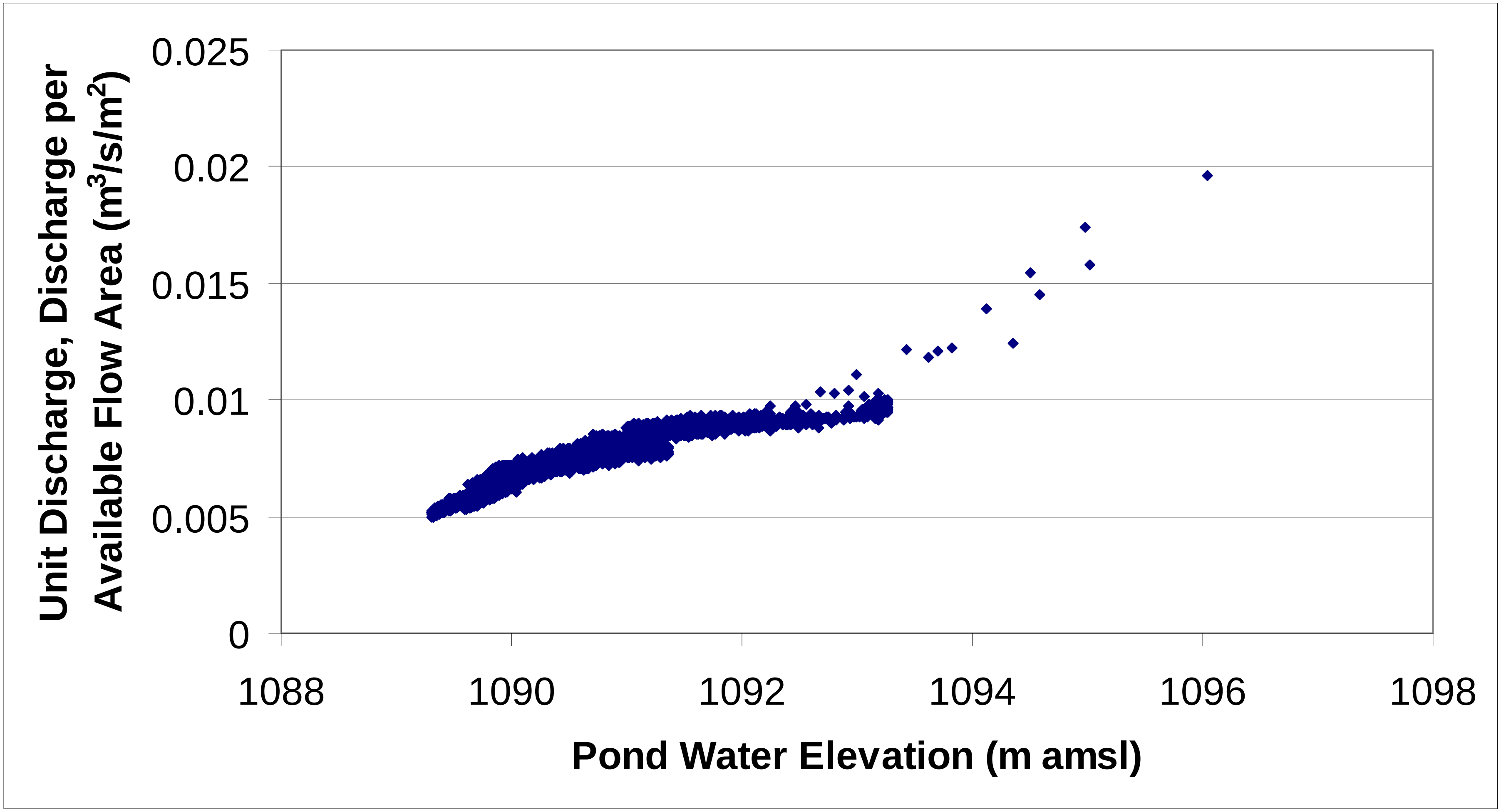

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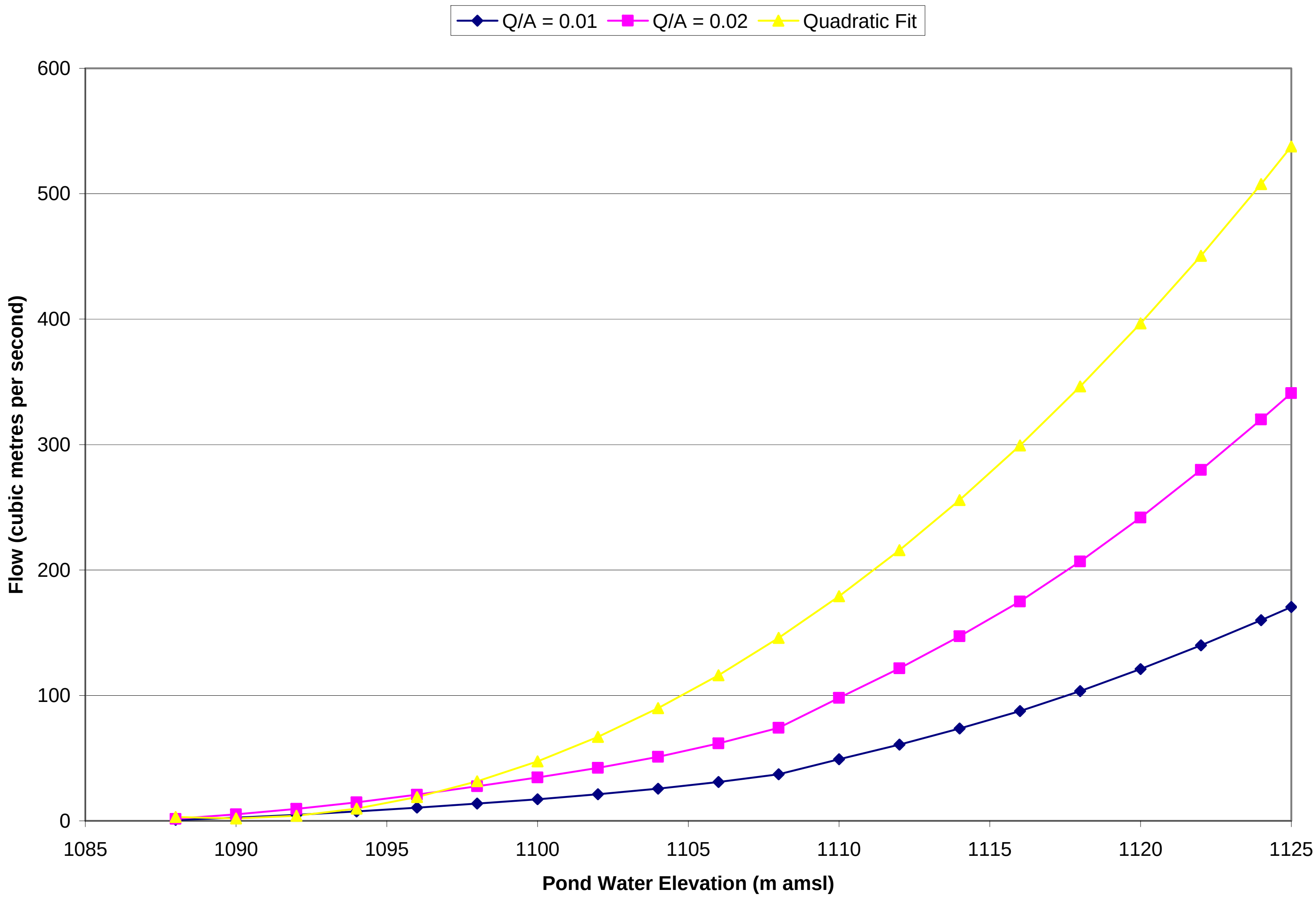
Project:	TASK 22F – 2005 ROCK DRAIN ANALYSIS				
Title:	UNIT DISCHARGE VERSUS POND WATER ELEVATION				
Project #: 0257-031-01	Date: JAN 2006	Scale: NA	Drawn: GWF	Approved: -	Figure: 6



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Project:	TASK 22F – 2005 ROCK DRAIN ANALYSIS
Title:	UNIT DISCHARGE VERSUS POND WATER ELEVATION

Project #:	Date:	Scale:	Drawn:	Approved:	Figure:
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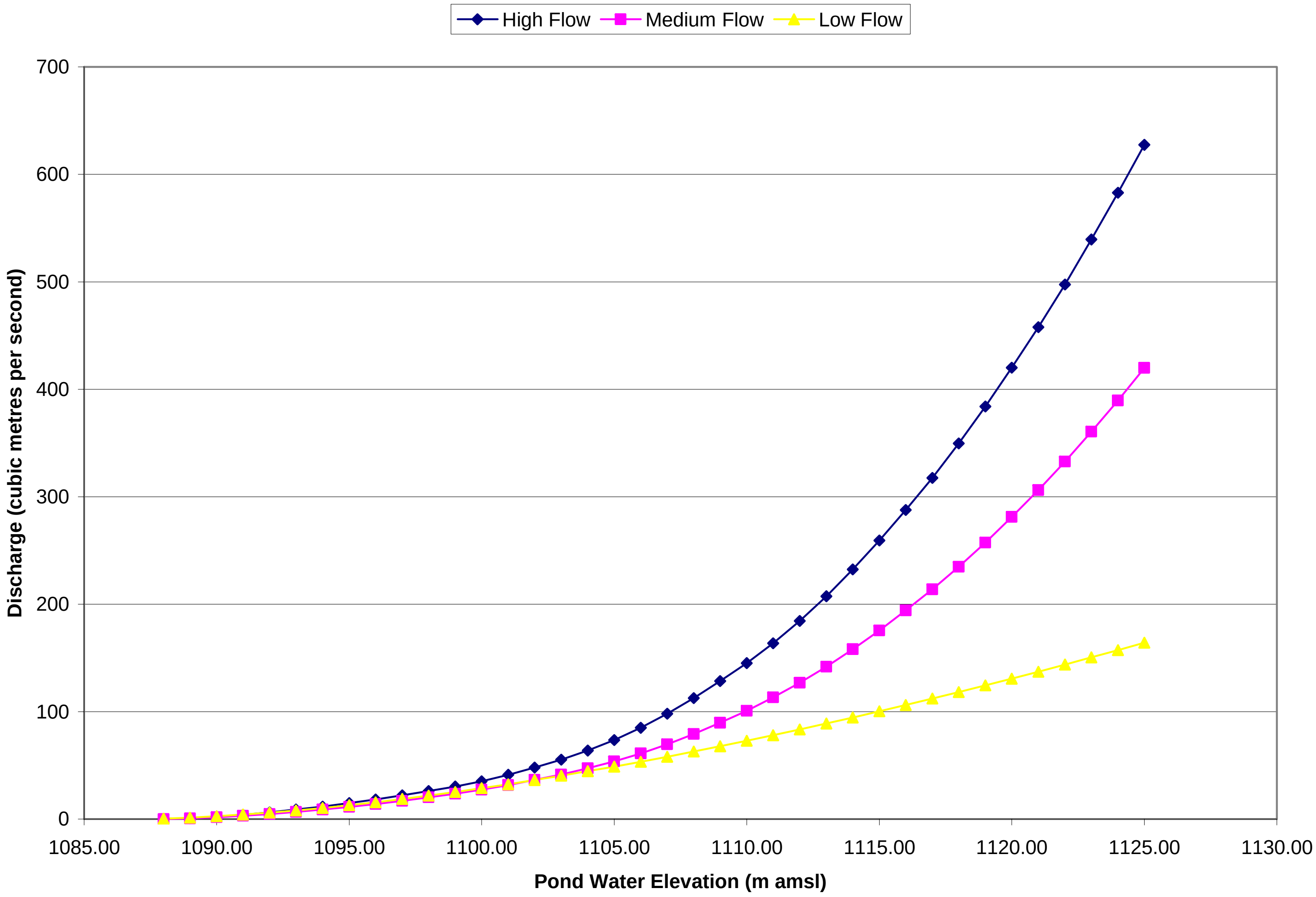

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Project:	TASK 22F – 2005 ROCK DRAIN ANALYSIS
Title:	ELEVATION DISCHARGE RELATIONSHIPS (WILKINS)

Project #:	Date:	Scale:	Drawn:	Approved:	Figure:
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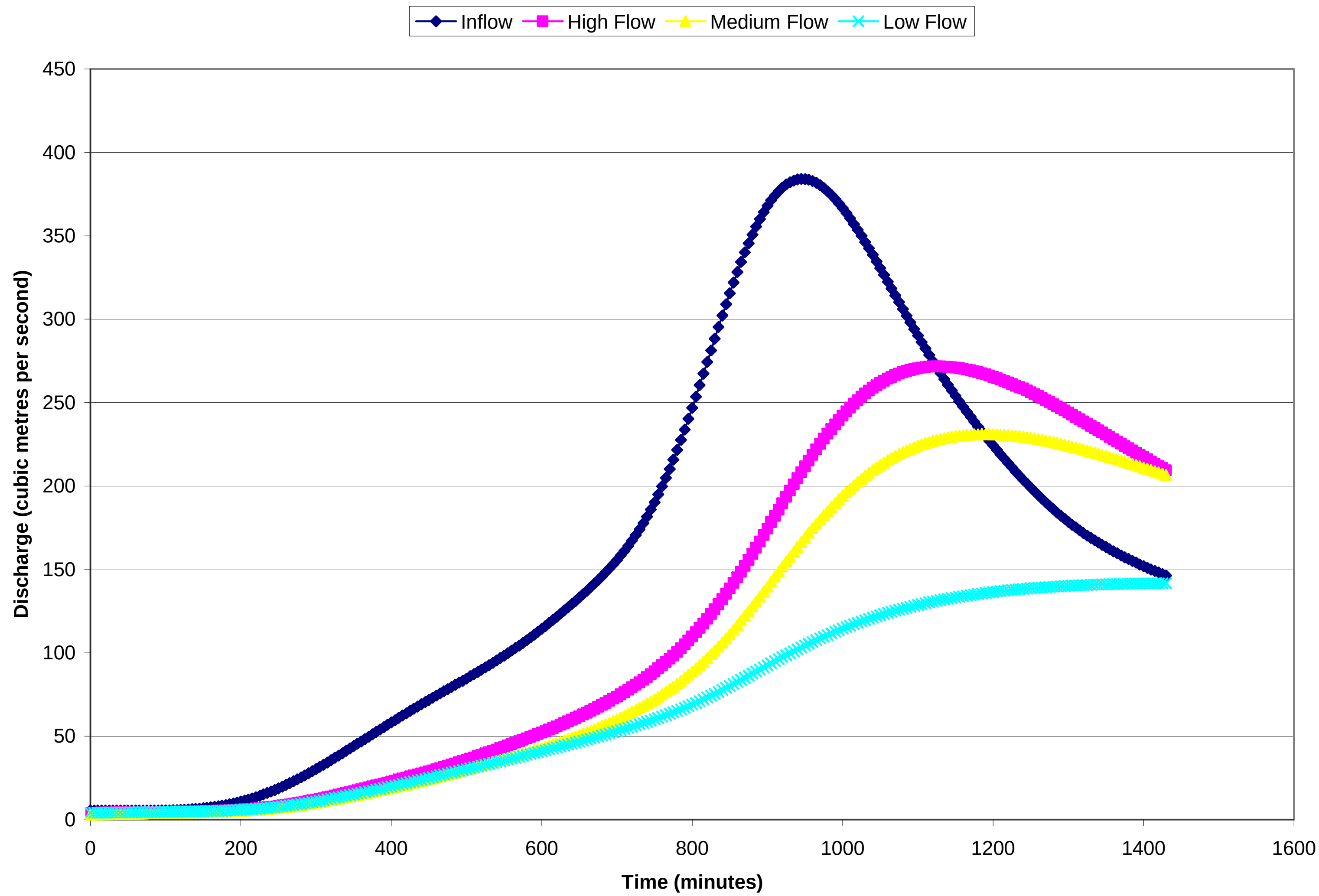

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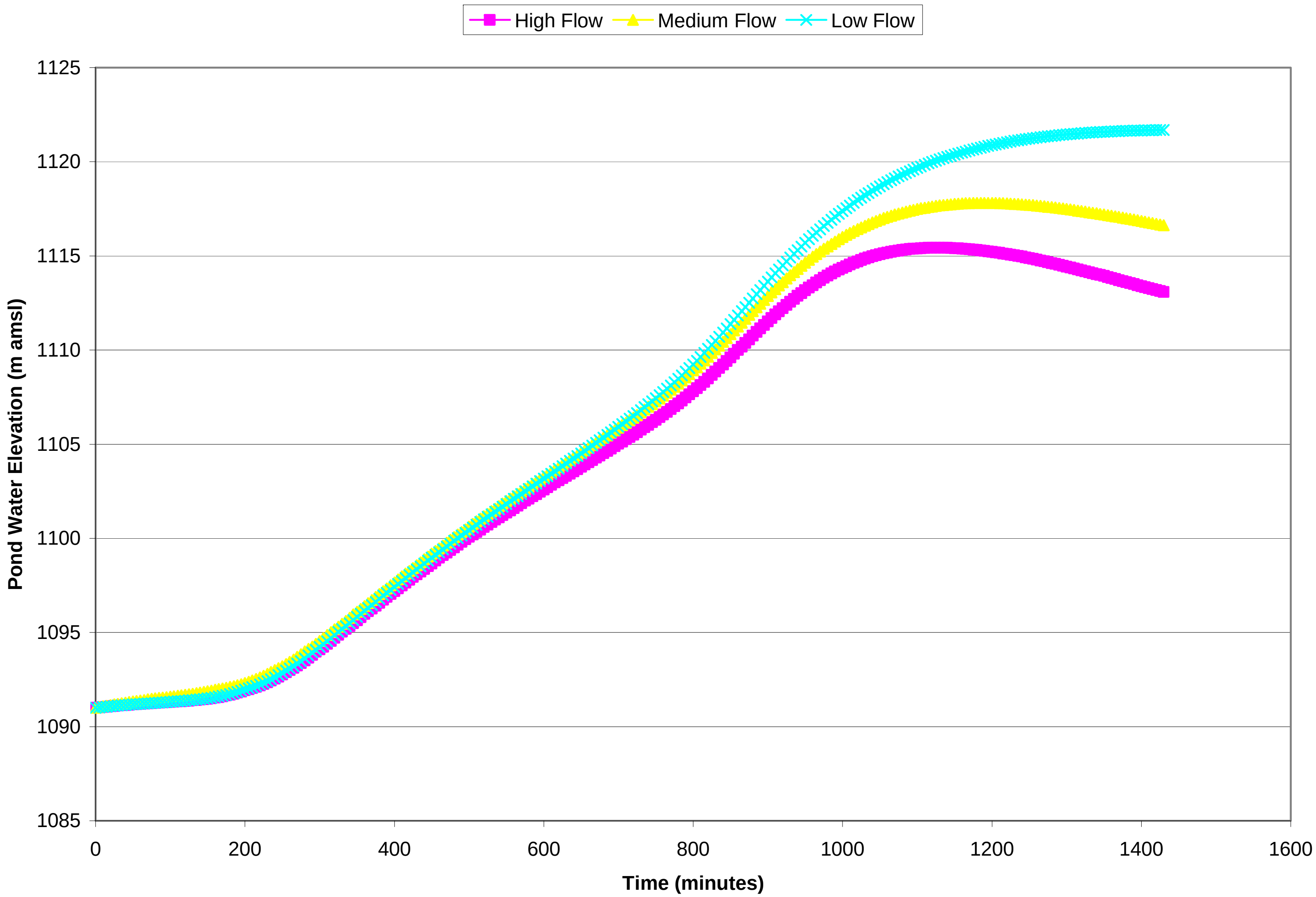
Project: TASK 22F – 2005 ROCK DRAIN ANALYSIS					
Title: PREDICTED DISCHARGE FROM NFRD DURING PMF EVENT					
Project #: 0257-031-01	Date: JAN 2006	Scale: NA	Drawn: GWF	Approved: -	Figure: 9



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Project:	TASK 22F – 2005 ROCK DRAIN ANALYSIS
Title:	PREDICTED POND ELEVATION DURING NFRD DURING PMF EVENT

Project #:	Date:	Scale:	Drawn:	Approved:	Figure:
0257-031-01	JAN 2006	NA	GWF	-	10